NIAGARA RAILWAY SUSPENSION BRIDGE

REPORT

ON THE CONDITION

OF THE

NIAGARA RAILWAY SUSPENSION BRIDGE.

1860.

REPORT

OF

JOHN A. ROEBLING,

CIVIL ENGINEER,

TO THE

PRESIDENTS AND DIRECTORS OF THE NIAGARA FALLS SUSPENSION AND NIAGARA FALLS INTERNATIONAL BRIDGE COMPANIES,

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Niagara Railway Suspension Bridge.

AUGUST 1, 1860.

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TO THE PRESIDENTS AND DIRECTORS

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NIAGARA FALLS SUSPENSION, AND NIAGARA FALLS INTERNATIONAL BRIDGE COMPANIES.

GENTLEMEN:

After an absence of two years, I have again visited the Niagara Railway Suspension Bridge, and have during a stay of three days, on the 18th, 19th and 20th of July, made a thorough examination of the work. I now present to you the following report:

The Niagara Bridge was opened for railway traffic on the 18th of March, 1855; the lower floor for common travel was completed and in use the year previous. The number of trains and trips of single engines, which at the present time pass over the Bridge in twenty-four hours, averages about forty-five. This great traffic accounts for the rapid wear of the rails, many of which require renewal.

After a thorough examination of all parts of the work, I am unable to report any change.

The camber of the floors and the deflection of the cables, as you well know, depend upon the temperature of the atmosphere. The relative level of the floors is the same as it was in 1855.

In order to be better enabled to judge whether the stiffness of the superstructure has been impaired by a five years' traffic, I placed a leveling instrument between the towers on the New York side, and observed the process of gradual deflection caused by five trains.

A train, composed of the engine "Essex," and tender, of 35 tons weight, drawing 10 empty cars, produced a deflection in the centre of	0,462	feet
A small engine, drawing 2 loaded passenger cars, 1 baggage car and 1 loaded cattle car,	0,540	"
Another light engine with 5 loaded passenger cars and 1 baggage car,	0,520	"
The engine "Essex" and tender alone,	0,315	"
The same engine returning with 8 loaded cattle cars, each holding 17 to 18 cattle of the largest size,	0,789	"

A short, but heavy train, such as the last, when in the center of the Bridge between the stays, produces the greatest deflection, comparatively. A longer train, loaded at the same rate and extending over the limits of the stays, deflects the work but little more. In proportion, as the ends of the floor are weighed down, the center is kept up. By comparing the above observations with those of 1855, we discover no essential difference. The great experimental train, which covered the whole Bridge with loaded cars, propelled by two engines, produced a deflection of ten inches. A similar train passed over now will do the same.

The extreme rise and fall of the floor, owing to the contraction and expansion of the cables, amounts to more than two feet. But the cables being at liberty to contract and expand, this process can never affect their strength.

In my report of 1855 I stated the aggregate ultimate strength of the 4 suspension cables at	12,000	tons.
Permanent weight, supported by cables,	1,000	"
Tension resulting,	1,810	"
Proportion of permanent tension to strength,	1 : 6.63	
Tension produced by a train of 250 tons,	452	"
Aggregate tension,	2,262	"
Proportion of working tension to strength,	1 : 5.30	

This liberal allowance of strength and freedom from vibration will insure the durability of the cables.

The question has been repeatedly asked, why trains are not allowed to pass over this Bridge at a higher rate of speed than five miles an hour? This limitation is looked upon as a sign of tacitly acknowledged weakness, and has been frequently referred to as a strong argument against Suspension Bridges for railway purposes.

This matter I discussed in my report of 1855, but I will explain again and more fully. The first great object of this limitation of speed is *safety*. Although it may look somewhat timid in this fast going age, to see freight trains move at the rate of five miles per hour, and passenger trains at even a less rate, yet when it is considered that this slow speed insures *absolute safety*, no matter what accident may happen to a train—the traveling community ought to be satisfied with this cautious arrangement. What would be gained by a higher speed? Nothing whatever. The bridge forms a link between two termini, and there is always time to make connections. Passengers will prefer to cross at a slow rate in order to enjoy the splendid scenery during the passage. The track is so constructed as to form a trough of three feet depth between the girders, into which a car or locomotive will instantly drop, the moment it breaks down or leaves the track—provided there is no great headway. Should such an accident happen to a train, the broken down car, engine or track will act as a powerful brake, and will check its motion. When planning the work, absolute safety was made the first condition, and the track has been constructed accordingly. I would also remark in this connection, that any further addition of fender-pieces to the track, as an additional means of safety, as has been proposed of late, would only prove an unnecessary incumbrance.

A greater speed than five miles per hour for passenger trains should never be permitted for the reasons stated.

But should a much heavier freight business have to be accommodated in the future, the speed of freight trains may be increased without injury to the work. All that will be necessary is, to keep the track in perfect order, and to maintain a continuous bearing at the rail joints to prevent concussions. I will further state here, that by an additional expenditure of $20,000, the stiffness of the bridge may be so far increased as to admit of the highest practicable speed of freight trains, without producing the slightest injurious effect upon the structure. I make this statement deliberately for the information of those professional and unprofessional opponents to Suspension Railway Bridges, who have made it their business to cast doubts upon the permanency of this work. I also expect to demonstrate this when resuming the works on the Kentucky River Bridge, on the Lexington and Danville Railroad, which, when completed, will form a single span of 1224 feet from center to center of towers, over a chasm of 300 feet deep.

The woodwork of the Niagara Bridge, being kept well painted and otherwise well protected, will last forty years and more. The old wooden St. Clair Bridge, at Pittsburgh, Penn., which I removed to make room for a new Suspension Bridge, recently completed, has stood exactly forty years. All its principal timbers of pine and oak, on removal, were found good and sound. A portion of this material, after being well tarred, has gone into the new suspension floor, and will no doubt render good service for another forty years.

My views of the durability of the cables have undergone no change since 1855; they have only been strengthened by additional experience. This being a subject of great importance and of general interest, I embrace this opportunity to express myself more fully, and thus perhaps to contribute towards a better understanding of the nature of iron.

The fact is well known, that wrought iron under certain conditions will undergo certain radical changes. And so will all kinds of matter. The material universe is not by any means constituted upon the principle of *immutability*. Material existence is but a theatre of change, of breaking down, of reduction and of reconstruction of the elements of matter. The Egyptian pyramids are even now undergoing a slow process of disintegration. The dry air of that region, slow in action, is still sure to do its appointed work. And as all human fabrics being but material constructions, will have to succumb to the same inexorable law, we can not expect that the Niagara Bridge will form an exception.

Two kinds of changes are known, which will affect the strength of iron and other metals. The one is wrought by the chemical process of oxidation, and can be guarded against effectually, and is so guarded in the Niagara Bridge. All iron and wire within reach are kept well painted, and thus preserved against rust. The anchor chains and their connections with the cables, inside of the anchor masonry and in the rock below, after three coats of paint, are protected by the cement grout, which forms a solid envelope, excluding air and moisture.

But aside from the mechanical protection thus afforded, I depend principally, as was explained in my report of 1855, upon the well known chemical action of calcareous cements in contact with iron. Oxygen has a greater affinity for lime than for iron. So long, therefore, as the cement will combine with oxygen, or in other words, has not become completely crystalized, which is a very slow process inside of heavy masonry, the iron will be protected. The cement, not exposed to the air, when setting slowly, has a tendency rather to expand than to contract; but suppose there should be cracks around the anchor bars, large enough to admit air and moisture. Water will then find its way through those cracks, but on reaching the iron, will be more or less impregnated with cement and thus add another protecting coat. The chemical principle, which I have explained here, I apply daily in my factory for the preservation of wire against dampness. I have also carried on direct experiments for a number of years, which have convinced me of the preserving property of calcareous cements in damp situations.

On examining recently the anchor bars of the Monongahela Suspension Bridge at Pittsburgh, built sixteen years ago, I found them perfectly preserved, as far as the cement, in which they are embedded, was removed. To satisfy yourself on this subject, I shall propose in a few years more, to remove the anchor blocks and to examine the upper links of the anchor chains of the Niagara Bridge. It should be remembered, that good cement grout, when not disturbed by any mechanical action or by a current of water, will set perfectly solid, and will become as hard as sand stone in course of time, and without shrinking. The anchor chains of the Niagara Bridge are, in my opinion, effectually guarded against oxidation.

But iron under certain conditions will undergo another change, which is not so well understood, and is indeed as yet a partial mystery. And this fact has been seized upon as an invincible argument against iron bridges generally, and against the Niagara Bridge especially. I refer to the supposed and popularly so-called *granulation* of fibrous wrought iron.

Although this subject has engaged my attention for a series of years, and I have taken pains to obtain correct information, I yet hesitate to express any decided opinions, that would cover the whole field of investigation. The question at large I consider open yet. This much only I believe to be settled, that good iron will undergo no change in course of time, unless it is acted on by great heat, or is under the influence of strong continuous vibrations under tension.

As an exception to this last proposition, may be cited the case of old anchors and chains, which, after being exposed on the ground or in the ground, a great length of time, had become considerably rusted and reduced in strength. Aside from rusting, magnetic influences were supposed to have been at work in destroying the strength of these irons. But it should be remarked, that none of these cases have been sufficiently well examined to warrant sound conclusions. It is true, that the earth forms a great magnet, whose magnetism is maintained by the sun; and that the magnetic condition of all metals is more or less depending upon the great parent magnet. A steel magnet, that has lost its power or tension, when buried in the earth, will be restored by its magnetic currents. But how far the cohesion and elasticity of wrought iron may be affected by these currents, we are yet ignorant of. When a bar of iron is drawn apart by a tensile strain, the fractured ends are magnetically excited, and will attract iron filings, at the same time that they become heated. Both phenomena, magnetism as well as heat, will always accompany the forcible rupture of iron, as can be readily ascertained by experiment. The same phenomena are also exhibited when iron is hammered cold, the heat in this case being more apparent than the magnetism.

The cohesion and elasticity of wrought iron, although different properties, appear to be closely related. In speaking of elasticity, I mean the natural elasticity, and not what is produced by the forced process of tempering. And here may be pointed out a marked, physical difference between steel and iron. While the hardening or tempering of steel can be carried to almost any degree, that of the latter can not.

Whatever destroys or impairs the elasticity of iron or steel, will also affect its cohesion. And this fact has also a significant magnetic bearing. Tempered or hardened steel possesses more tensile strength than soft steel. Now when tempered steel looses its hardness by annealing, it assimilates nearer to soft iron in its relation to magnetism. Red-hot iron is not attracted by a magnet, while a steel magnet entirely looses its magnetic properties on being heated red hot. Another remarkable fact is, that artificial as well as natural magnets, when *overloaded*, become weakened. And so does the cohesion and elasticity of an iron or steel bar become weakened by overloading.

The limit of elasticity, or of the *recuperating* force, as it might be termed, of iron and steel is generally stated at one-third of their ultimate strength. I am of the opinion, that this is much *over*-estimated for soft puddled irons, and *under*-estimated for good hammered charcoal irons, and still more for steel.

The force which holds together the molecules of iron, is termed cohesion. Heat will expand iron, and when applied intensely and continuously, will melt it, and will thus destroy all cohesion, and at the same time all elasticity and all magnetic tension. It follows then that heat of a certain degree is opposed to cohesion and elasticity. And this explains why large masses of wrought iron, when being forged, and thus subjected for a considerable length of time to an annealing process, will, in the centre, become greatly reduced in cohesion and elasticity. The previously existing fibre in the faggots will change into a coarse crystaline texture, because the iron being in a pasty and nearly molten state, and the mechanical effect of hammering being confined to the surface, and not penetrating to the centre, the formation of large crystals will be left undisturbed. Broken car-axles sometimes appear to have undergone a similar change. The fact is, that they generally exhibit a crystaline fracture. But I suspect, that many new axles, although manufactured out of fibrous roughbar, will, when finished and broken *before* they are used, also exhibit a crystaline fracture. In my own practice I have witnessed the fact that an experienced manufacturer, anxious to satisfy me, did not succeed in manufacturing round bolt of four to five inches diameter out of good fibrous roughbar, without producing a crystaline texture in the centre. The oftener he piled the iron, the worse the result. On the other hand, I never heard of a failure when the bolt was forged entire under the hammer out of good and well worked, and thoroughly hammered charcoal blooms, their rough ends cut off.

The most fibrous bar iron may be broken so as to present a granular and somewhat crystaline fracture, and this without undergoing any molecular change in the texture. Take a fibrous bar, say ten feet long, but the longer the better, nip it in the centre all around with a cold chisel, then poise the bar upon the short edge of a large anvil, and a short piece of iron, placed eight or nine inches from the edge on the face of the anvil, then strike a few heavy blows upon the nip, so that each blow will cause the bar to rebound, and to vibrate intensely, and the result will be a granular and somewhat crystaline fracture. Now take up the two halves, and nip them again all around, about one or two inches off the fractured ends, break them off by easy blows over the *round* edge of the anvil, and the fibre will appear again. This experiment proves that a break, caused by sudden jars and intense vibration, may show a granular and even crystaline fracture, without having changed the molecular arrangement of the iron. All fibres are composed of mineral crystals, drawn out and elongated or flattened; and the fracture may be produced so as to exhibit in the same bar, and within the same inch of bar, either more fibre or more crystal. But a coarse crystaline bar will under no circumstances exhibit fibre; nor will a well worked out fibre exhibit coarse crystals.

My own view of this matter is, that a molecular change, or so called *granulation* or *crystalization*, in consequence of vibration or tension, or both combined, has in no instance been satisfactorily proved or demonstrated by experiments.

I further insist that crystalization in iron or any other metal *can never take place in a cold state.* To form crystals at all, the metal must be in a highly heated or nearly a molten state.

On the other hand, I am witnessing the fact daily, that vibration and tension combined will greatly affect the strength of iren *without* changing its fibrous texture. The cohesion and elasticity of wire and wire rope will be rapidly destroyed by great tension and vibration combined. Whether I shall be able to account for it or not, *there stands the fact.* But what is true of iron wire, applies with equal force, and when all circumstances and conditions are duly proportioned, with even greater force, to larger masses. The extensive opportunities which my pursuits offer, to make experiments and observations on wire and wire rope, authorize a positive expression on this subject. A great deal of fancy speculation has been indulged in of late years on this question of granulation and crystalization, but generally by men whose opinion can have no weight.

Now, while the fact remains that iron and steel will lose their strength by vibration and tension, it is proper to state, also, in this connection, that this loss of strength bears a due proportion to the extent and duration of the vibration and tension. Wire ropes may lose their strength by three months service, *without* exhibiting much wear; and they may also last ten years, running all the time, and be greatly worn, before their strength is so far reduced as to be unfit to do duty. I will state here, that there are now ropes of my manufacture on the inclines of the Morris Canal, which have run nine years. This great durability is owing to comparative absence of vibration, in consequence of slow speed and good machinery, although a high tension is maintained.

The greater the elasticity and cohesion of the iron or steel, the better it will support vibration and tension, always provided, that the extent of this vibration and the amount of tension are kept within safe limits. Witness as examples the durability of watch-springs, piano wire, sofa and wagon springs, etc., etc., etc.

Wrought-iron, that has become brittle, as for instance chain, car axles, wire or wire rope, on being annealed, will have its softness and apparently also its strength restored. As far as softness is concerned, this is correct; but in regard to strength, when applied to wire or wire rope or to fine chains, it is a mistake. Soft annealed wire possesses only half the strength which hard wire has, and is without any elasticity. But wire rope without elasticity is worthless; very little work will make it brittle again and worse than before. It is different with heavy chains and with car-axles. Made of indifferent material, crystaline or brittle when new, they will be greatly improved by an annealing process at the very beginning; and if this process is repeated from time to time, their lifetime may be prolonged. I maintain that a good car-axle, made of good material, and finished at the proper heat, by hammering or rolling, is stiffer and stronger than the same axle, when again subjected to annealing without hammering or rolling. Annealing restores softness, but at the same time reduces cohesion and elasticity. To restore the iron of a brittle car-axle fully, can only be done by a full heat, with hammering or rolling, which of course will reduce its diameter.

The opinion prevails, that a well drawn out fibre is the only sure sign of tensil strength. This however is true only when applied to *ordinary* qualities of bar or rail iron. The fact is different with good charcoal irons and with steel. The greatest cohesion is accompanied by a fine close-grained uniform appearance of texture, which, under a magnifying glass, exhibits fibre. The color is a silvery lustre free from dark specks. The finer and more close-grained the texture, the nearer the iron approaches to steel. Those who are familiar with good Swedish or Norway irons, will support these statements. These facts alone should be sufficient to disprove the erroneous notion that good iron and steel, which should always be granular, will become so only by vibration, and will thereby lose their strength. But it is important to keep in mind the distinction between a fine uniform granular fracture, and a coarse crystaline fracture. Where coarse crystalization appears, there is a want of contact and compactness, consequently of cohesion and strength generally.

Wire cables, car-axles, piston-rods, connecting-rods, and all such pieces of machinery, which are exposed to great tension as well as torsion and vibration, should be manufactured of iron which not only possesses great cohesion, but also a high degree of hardness and elasticity. The best car-axles now in use, are those made of soft steel by Krupf, in Germany. This steel is manufactured from the spathic ore or natural steel ore, of the celebrated mines at Muessen in Siegen, Prussia. A correct report on these axles was given to me by one of the Prussian Commissioners of Railways, in whose district Krupf's works are located. They are safe in cold weather and seldom known to break. This proves that soft steel with more of a granular texture than fibre, possesses a much greater elasticity and strength than the best fibrous iron; and it also furnishes another strong proof against the granulation theory, so much credited in this country.

It may be objected, that steel is a different metal from iron. But all irons and steels are only so many different alloys of the same metal. There is no essential difference between the two. What constitutes the true chemical and physical difference between the two varieties, is not so clear. The old idea, that steel owes its distinguishing properties to a greater per centage of carbon alone, is no longer maintained. There are not two metallurgists who agree as to the proper per centage of carbon that good steel ought to contain. The ablest chemists who have analyzed iron and steel, from Karsten and Berzelius down to the present day, have not been able to give us a correct analysis of these two metals. Mr. Mushet, jun., has recently shown that the excellence of steel is depending upon the presence of Titanium, a substance formerly overlooked. But so long as the chemistry of iron and of steel is still without a sure basis, we must fall back upon well discerned empyrical facts.

The capacity of irons to resist vibration and tension differs much in different qualities, and still greater is this difference when the irons are exposed to a very cold temperature. The tubular bridge at Montreal will not last as long as one in Great Britain of the same dimensions, material and workmanship, and rendering the same service; and still less than the tubes over the Nile in Egypt. One hard winter in Canada will be as trying to the structure as ten years are in Great Britain.

In order to examine the fitness of various qualities of iron for the manufacture of wire rope, I undertook, during the hard winter of 1856, at my establishment at Trenton, a series of experiments, when the thermometer was five to ten degrees below zero. The samples for testing, about one foot long, were reduced in the center to exactly three-quarters of an inch square, and their ends left larger, were welded to heavy eyes, making in all a bar of three feet long. Thus prepared, they were thrown outside of the mill, covered with snow and ice, and left exposed for several days and nights. Early in the morning, before the air grew warmer, a sample, enclosed in ice, would be put into the testing machine, and at once subjected to a strain of 26,000 pounds, the bar being suspended in a vertical position, left free all around. A stout millhand, armed with a billet of one and a half inch in diameter and two feet long, then struck the sample horizontally a number of blows, hitting the reduced section as hard as he could. The blows were counted and continued until rupture took place. Care was taken to maintain a tension of twenty-six thousand pounds during this test, by screwing up the lever, while the sample kept stretching. Other means for producing vibration were attempted, but none proved so effective as the hitting with an iron bolt. I would remark here, that most of these irons would support from seventy to eighty thousand pounds per square inch; and that good samples of three-quarters of an inch square, would support a strain of twenty-six thousand pounds for a whole week, with no visible stretching, provided all vibration and jarring was avoided. But the least jar would produce a permanent elongation.

Without going into the details of these interesting and instructive experiments, I will only state that the number of blows which the different samples resisted, when encased in ice, ranged from three to one hundred and twenty. Inferior qualities of a crystaline texture would break at the third or fourth blow. Good samples of refined puddled bar resisted very well, and went up to sixty blows, while the better qualities of hammered charcoal irons, supported up to one hundred and twenty blows, stretching and drawing all the time. Indeed, it seemed a wire-drawing process on a rough scale. On the tension being reduced to twenty thousand pounds, some good samples resisted the almost incredible number of three hundred blows, before breaking.

Such qualities of iron may be depended upon for the construction of wire cables and car-axles. They will be safe at the North Pole, while inferior qualities may answer very well in warmer latitudes.

Well observed facts of the durability of irons, when exposed to tension and vibration, are of more value than speculative opinions. I will here record a few more facts, experienced by myself.

In 1844 I removed the old timber aqueduct over the Allegheny river at Pittsburgh, the heaviest work of that description in the United States, consisting of seven spans of one hundred and fifty feet reach. It had stood fourteen years. All the suspension bars taken out of the old trusses and arches, and originally made of good puddled iron, on being tested and worked up into bolts for the new wire suspension aqueduct, proved of good quality, as good as such irons generally are.

During the great fire at Pittsburgh in 1845, the old Monongahela bridge, of eight spans, a heavy Burr structure, burned down. I contracted to put up a suspension bridge, and accepted all the old materials, which were not consumed, including about thirty tons of hammered charcoal iron of excellent quality. This iron, after a severe usage for over thirty years, was found so good that I had it all drawn into wire. Every bar was good for sixty thousand pounds per square inch, as strong and tough as it ever could have been before going into the bridge. The old structure was loose and limber, producing considerable vibration on all vertical bars.

On excavating for the southern anchorage between the old wing-walls of the old Monongahela bridge, a number of round bars of one and a quarter inches diameter, about forty feet long, good puddled fibrous iron, was taken up. They had served as tie bars, to keep the retaining walls from spreading. Screwed up tight, they had been under ground about twenty-five years, embedded in clay. The outside rust, firmly combined with clay and sand, appeared to have formed a protective coat. At any rate the strength of the iron had not suffered at all from oxidation, its quality was as good as any puddled bar manufactured at the present day.

Last year, while removing the old St. Clair Street Bridge over the Alleghany River at Pittsburgh, to make room for a new Suspension Bridge, since completed, I examined the old iron with considerable interest and care. All this iron had been manufactured about forty-one years ago, and had been the result of the first attempts at puddling ever made west of the Alleghany Mountains. The manufacturer, who is still living, informed me that in those days puddling was not well understood, and that, although the stock was good cold blast charcoal pig, the iron turned out of a highly crystaline texture. It proved so on its fracture, but of a good color, the texture was uniform and not coarse. On being heated and drawn down to half its size, it made a strong fibrous iron; all it wanted was work. There was not one fibrous bar in the whole lot of suspension bars; they were all alike crystaline and brittle in texture. This iron had, from the manufacturer's own testimony, undergone no change; it was as crystaline on the last day as it was on the first. But there was another quality of iron in the same structure. The straps and bolts which connected the chords with the posts and braces, had been manufactured of a good quality of hammered charcoal iron, and a most capital iron it proved, after forty years' service.

I will also draw attention to those interesting experiments, made recently by Mr. Albert Fink, on a number of suspension bars, taken out of his bridges on the Baltimore and Ohio Railroad, for the purpose of testing their strength after seven years' service. These tests exhibited a rate of strength, which is only possessed by good iron, and led Mr. Fink to the conclusion that seven years' wear had not affected the bars.

All irons form alloys of pure iron, mixed with carbon and other impurities. A certain amount of impurities in the shape of good cinder appears to be necessary to impart strength and cohesion to this metal, and also to make it malleable, and to give it welding properties. The purer the iron is, the higher the heat at which it will weld. Compare for instance good Swedish iron with common puddled bar. While the latter will weld at a low heat, the former requires a much higher heat. Compare their fracture and color. The good Swedish bar will exhibit either a fine granular appearance or fibre, accompanied by a silvery lustre, showing comparative purity; the puddled bar will be of a dark color, with a graphit lustre, and will show a coarse texture or loose fibre.

During the process of puddling, as well as of blooming, the melted pig-iron is mixed with cinder, and this mixture, which will adhere by cohesion, prevents the formation of large crystals, which is the tendency of pure iron in a molten state. Now by working (bringing to *nature*, as the puddler calls it,) this mixing and crystalization is promoted. The subsequent squeezing and rolling of the puddled ball, or the hammering and shingling of the bloom, will have the effect of condensing, laminating, reducing and drawing out these crystals, at the same time removing and squeezing out the superabundant cinder from between the metallic crystals. Thus the drawn out fibre is composed of an aggregate of pure iron threads and leaves, enveloped in cinder.

Pure iron as well as very impure iron is weak; the maximum strength and toughness is obtained by a certain mixture of pure iron with carbon and cinder, thoroughly worked and incorporated. When the fibrous and laminar aggregation becomes so dense as to be fit for the manufacture of steel, then are by this very process sufficient impurities expelled, and the greatest degree of cohesion is obtained, Hence strong steel can only be made of strong iron, no matter what chemicals may be administered during the process.

Keeping the above process before our mind, we may now understand why even the best fibrous wrought-iron, when exposed to long continued vibration under tension, or to tortion, bending or twisting, must inevitably become brittle, *because the iron threads and laminae become loosened in their cinder envelopes.* But the cohesion between the iron and its cinder once destroyed, and its strength is gone. Now whether cohesion is the result of magnetic attraction (according to Fraday,) or otherwise, this process appears to be purely mechanical. But let the explanation, which is here offered, be correct or not, the fact remains that fibrous iron and all kinds of iron and steel, will be rendered brittle by vibration and tension, or by bending and twisting, *without* undergoing any mysterious change in its molecular arrangement.

It is only within the last one hundred years that wrought-iron has become a *necessity* on public and private works. Large structures, entirely composed of iron, are of a still more recent date. Long experience on a large scale is therefore wanting. But as far as it goes, the opinion is fully sustained, that good iron, not overtaxed by tension and vibration, and otherwise preserved, will prove one of the most durable building materials at our disposal.

The Menai Chain Suspension Bridge has now stood about thirty-six years, and is still considered a safe work, although it has, for the want of stiffness, on several occasions, suffered severely from gales. The old Wire Suspension Bridge, at Friburg, in Switzerland, has been in use about twenty-seven years, but it does not possess enough of strength and stiffness to guarantee its safety much longer in its present state.

It should be remembered that there are many suspension bridges in this country, as well as in Europe, built without any regard to stiffness, and are therefore constantly subjected to vibration, which must greatly limit their durability.

The cables of the Niagara Bridge, on the other hand, are free from vibration, consequently will last as long as the nature of good wrought-iron will permit, when subjected to a moderate tension, not exceeding one-fifth of its ultimate strength. This durability I am unwilling to estimate at less than several hundred years.

Iron has emphatically become *the material of the age.* Upon its proper use the future comfort and physical advancement of the human race will principally depend. It will yet be the harbinger of peace, as already it has given us the means of locomotion and of intelligent intercourse. The subject of this paper is therefore of great importance and is entitled to a truthful consideration.

I will close this report by repeating once more, that the cables of the Niagara Bridge are made of a superior quality of material; that they possess an abundance of strength; that they are free from vibration; that they are well preserved and taken care off; and consequently that they may safely be trusted for a long series of years.

Respectfully submitted, by

Your obedient servant,

JOHN A. ROEBLING,

Civil Engineer.

Trenton, N. J., Aug. 1, 1860.